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(54) Title: EXTENSIBLE SELECTION FEEDBACK AND GRAPHIC INTERACTION

(57) Abstract

Computer software, process, and object-oriented objects that decouple the details of accessing graphical data from the details of processing and iterating through the graphical data. The invention first receives a filter routine and a funnel routine, and passes an iterator, that enumerates over the graphical data, to the funnel routine. Then the invention repetitively calls both the filter and funnel routines to enumerate over the graphical data. The filter routine selects, orders and returns graphical data. The funnel routine processes the graphical data and also can pre-terminate enumeration. Developers have the capability to extend the invention by providing their own versions of the filter and funnel routines and by modifying the enumeration.

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EXTENSIBLE SELECTION FEEDBACK AND GRAPHIC INTERACTION

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CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

This patent application is related to patent application number 8/146,631 entitled *Graphic Editor Framework System*, by Robert Seidl, filed October 29, 1993, and assigned to Taligent, the disclosure of which is hereby incorporated by reference. This patent application is also related to patent application number 08/295,442 entitled *Object-Oriented Global Cursor Tool*, by Robson, Watanabe and Watson, filed 08/23/94, and assigned to Taligent, the disclosure of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

The instant invention generally relates to an extensible mechanism to provide application developers with the facilities to implement customized selection feedback facilities used with a graphical user interface (GUI). The instant invention encompasses apparatus, methods, and software objects that provide this extensible mechanism to an application developer. These facilities enable an application developer to provide a user of a computer pointing device with selection feedback for graphic interaction with the computer. The invention is disclosed in a preferred embodiment using a popular object-oriented programming language, C++, but the principles are applicable to other computer programming languages both object-oriented and procedural.

Description of the Prior Art

Background

Object-oriented programming (OOP) is the preferred environment for building user-friendly, intelligent computer software. Key elements of OOP are data encapsulation, inheritance and polymorphism. While these three key elements are common to OOP languages,

most OOP languages implement these three elements differently. These elements are described in the above referenced applications (08/295,442 & 08/295,442).

Examples of OOP languages are Smalltalk, Object Pascal and C++. Smalltalk is more than a programming language; it can be characterized as a programming environment. Smalltalk was developed in the Learning Research Group at Xerox's Palo Alto Research Center (PARC) in the early 1970s. In Smalltalk, a message is sent to an object to evaluate the object itself. Messages perform a task similar to that of function calls in conventional programming languages. The programmer does not need to be concerned with the type of data; rather, the programmer need only be concerned with creating the right order of a message and using the right message. Object Pascal is the language used for Apple's Macintosh® computers. Apple developed Object Pascal with the collaboration of Niklaus Wirth, the designer of Pascal. C++ was developed by Bjarne Stroustrup at the AT&T Bell Laboratories in 1983 as an extension of C. The key concept of C++ is a class, which is a user-defined type. Classes provide object-oriented programming features. C++ modules are compatible with C modules and can be linked freely so that existing C libraries may be used with C++ programs. The most widely used object based and object-oriented programming languages trace their heritage to Simula developed in the 1960s by O-J. Dahl, B. Myhrhaug and K. Nygrad of Norway. Further information on the subject of OOP may be had by reference to *Object-oriented Design with Applications* by Grady Booch, the Benjamin/Cummings Publishing Co., Inc., Redwood City, Calif. (1991).

Data encapsulation, inheritance and polymorphism facilitate creation of graphical user interfaces (GUI). GUIs are typically characterized by a windowing environment having icons, pointing cursors and menus. A GUI is constructed by enhancing classes of an object-oriented GUI framework by using data encapsulation, inheritance and polymorphism.

Another aspect of object oriented programming is a framework approach to application development. One of the most rational definitions of frameworks comes from Ralph E. Johnson of the University of Illinois and Vincent F. Russo of Purdue. In their 1991 paper, *Reusing Object-Oriented Designs*, University of Illinois tech report UIUCDCS91-1696 they offer the following definition: "An abstract class is a design of a set of objects that collaborate to carry out a set of responsibilities. Thus, a framework is a set of object classes that collaborate to execute defined sets of computing responsibilities." From a programming standpoint, frameworks are essentially groups of interconnected object classes that provide a pre-fabricated structure of a working application. For example, a user interface framework might provide the support and "default" behavior of drawing windows, scrollbars, menus, etc. Since frameworks are based on object technology, this behavior can be inherited and overridden to allow developers to extend the framework and create customized solutions in a particular area of expertise. This is a major advantage over traditional programming since the programmer is not changing the original code, but rather extending the software. In addition, developers are not

blindly working through layers of code because the framework provides architectural guidance and modeling but at the same time frees them to then supply the specific actions unique to the problem domain.

A framework may thus be regarded as a system that provides an implied network of responsibilities between objects, provides for inheritance between classes of objects (e.g., data and methods of superclasses at higher hierarchical levels of classes of objects), and provides for calling of libraries in response to events. A system formed as a framework may also be customized by the addition of objects that perform more specific functions and which may also override functions provided by the framework. Machine-specific and device-specific objects in various classes and subclasses of the framework allow the framework, itself, to be machine- and device-independent and of generalized applicability. Further, a particular framework is characterized by the interrelationships it establishes between objects and classes of objects in terms of division of responsibilities and inheritance and the functionality it thus achieves. A framework, itself, is also useful as a template for the development of specific applications wherein customization and functional overrides may be provided as specific objects.

The class or object in object-oriented programming design encapsulates structure (e.g., data) and behavior (e.g., so-called "method functions") that operate on the structure. In object-oriented design, an interface is an outside view of a class or object of interest. The interface allows other objects to interact with the object of interest while hiding the structure and behavior of the class or object of interest. Additionally, all objects descending from a base class inherit the properties of the base class and thus will have the same properties thereof and are polymorphic with respect to base class operations. Hence, objects descending from the base class can be used to represent an instance of the base class and can be substituted whenever a base class is called.

The Graphic Editor Framework (GrafEdit), described in application 8/146,631 referenced above, provides an object-oriented framework for developing applications with graphical editing capabilities. This framework provides a plurality of classes that define default interactions between the subsystems of the system architecture and the application using the framework; and between the application and other applications. These classes provide methods for drawing, interaction, manipulation and presentation of graphic objects and data. If the application developer desires more complicated features or functions, the application developer can customize and override GrafEdit classes to provide the desired functionality. So long as the developer's customization is encompassed within the framework architecture, it is allowed.

By using a graphical user interface (GUI), the computer user interacts with a graphical display by using a pointing device (e.g., a mouse). The user is able to specify graphical items, rendered by the GUI on a display screen, by moving the pointing device to "point to" and pressing a button to "select" a graphic. Once the graphic is selected its appearance changes to indicate to the user that the selection was successful. A selection feedbacker object or routine

creates the altered appearance of the selected graphics. Selected graphics have a semantic meaning that non-selected graphics lack. Therefore, a selected graphic can be the target of an operation that affects the selected graphic.

Along with providing selection feedback to the computer user, the changed appearance of the selected graphic can indicate active control areas that are attached to the selected graphic. These control areas allow the user to perform some command operations on the selected graphic. An example is when a graphic's appearance is changed by adding pointer-sensitive "handles" to the graphic. These handles allow the user to interact with the graphic by invoking an operation by pointing to the handle and "dragging" it. The handle follows the pointer while the pointer moves. During the drag interaction, or when the drag interaction completes, the application performs a specified operation on the graphic.

Often the application developer uses a graphical framework to implement a GUI as described in application 8/146,631 referenced above. These frameworks generally provide the application developer with a limited number of selection feedbackers and graphical operations. These operations generally include moving, copying, pasting and duplicating the graphic. Although a limited number of selection feedbackers helps enforce GUI look and feel consistency, it also restricts the developer's implementation options. Another problem with GUI frameworks is the difficulty in providing special user interactions (feedback and graphical operations) that are dependent on which graphic was selected. An example of this difficulty is if one graphic needs a special user interaction to change the color of the graphic while other graphics require only the standard handle and SRT user interaction. (The handle and SRT selection feedbackers are described below and in application 8/146,631 referenced above.)

There has been a long felt need in the art for an application developer to be able to provide unique and/or custom graphical selection feedback to a user of a graphical user interface. Finally, there has been a long felt need for an application developer to be able to implement custom interaction with a selected graphic beyond the interactions provided by a graphical framework.

Definition of Terms

Active iterator: An object that controls progression through a collection of objects or data structures returning an item of interest (a relevant item).

Class: A set of objects that share a common structure and a common behavior (from *Object Oriented Design with Applications* by Grady Booch, hereinafter OODA).

Command Operation: An operation, supported by a computer application, evoked by a computer user. In the context of the instant invention, a command operation is performed on selected graphics.

Enumeration: An operation that iterates over a collection of objects or data structures. Usually implemented by using an active iterator.

Feedbacker: A short-hand term for Selection Feedbacker (see below).

Framework: a group of interconnected object classes that provide a pre-fabricated structure of a working application.

Graphic interaction: defines the behavior that results when the user interacts with a pointing device, e.g. mouse, within the area of a graphic, even if the graphic, or portion thereof, is not visible.

Inheritance: A relationship between classes, wherein one class shares the structure or behavior defined in one or more other classes (OODA).

Methods: Routines (program logic) contained within an object that implement operations on the object's data.

Object: software entities comprising data structures and operations on the data contained therein.

Object oriented programming: is a manner of implementation wherein programs are organized as cooperative collections of objects, each of which represents an instance of some class, and whose classes are all members of a hierarchy of classes united via inheritance relationships (OODA).

Passive Iterator: An object that processes items passed to it by a caller.

Selection feedback: is a visual distinction of some subset of the graphics displayed by an application to indicate to the user which graphics are the target of some operation.

Selection Feedbacker: is used to refer to the graphical object that, when drawn in front of, or in place of, a selected graphic, provides graphical feedback that indicates the graphic is selected. The selection feedbacker may add additional interactive capability for manipulating the selected graphic (e.g. to scale, rotate or translate it).

Subclass: A class that inherits from one or more classes (OODA).

The Context

This invention is directed towards the Graphic Editor Framework (GrafEdit) and other similar graphical application architectures that need support for extensible selection feedback and graphic interaction. GrafEdit is described in application 8/146,631 referenced above.

The Problem

Figure 1a depicts two example selection feedbackers applied to a graphic. The graphic for this example is an oval 40 shown in three views (a), (b), and (c). The oval 40 in view (a) represents a non selected graphic. View (b) shows one common style of selection feedback. Once the user has selected the oval 40, handles 41 appear on the graphic. The user can move a pointing device onto one of the handles 41, press a key or button and drag the handle to scale the selected graphic (the oval 40 in this example). View (c) shows the Scale-Rotate-Translate (SRT) feedbacker. If the SRT feedbacker is associated with the oval 40, once the user selects

the oval 40 a grid appears containing feature sensitive areas. The user can manipulate the corner areas, two of which are labeled 42, to scale the oval 40 in the same manner as the handles in view (b). The user manipulates the feedbacker edge regions 43 to rotate the oval 40. Finally the user can drag the center area of the feedbacker 44 to move the graphic. The SRT feedbacker is described in more detail in application 8/146,631, referenced above.

In GrafEdit. the selection feedbacker object is a separate graphical object from the selected object. Thus, the underlying graphic is not modified to display the selection feedbacker. Instead, another graphical object is displayed in front, or in place of, the selected graphic. This is different from the prior art wherein a graphic object draws itself differently to provide selection feedback.

The problem solved by the instant invention is that developers have not been able to easily implement custom selection feedbackers or provide custom graphic interaction within a GUI framework because the framework architecture was not extensible. The GrafEdit framework, for example. provided only a single selection feedbacker (the SRT feedbacker). As useful as this feedbacker is. it does not provide all the functionality needed by application developers. Further, there could be only one selection feedbacker for all selected graphics. That single selection feedbacker was drawn on top of all the displayed graphics. This prevented selection feedbacker strategies that used color shifting or inverting selected graphics.

Application developers need the ability to easily implement custom selection feedbackers and specialized graphical operations for user-selected graphical objects. This need extends beyond GrafEdit because any GUI development package, whether or not a framework, will have similar architectural problems. The instant invention discloses and claims a design that supports extensible selection feedback and interaction in GUI architectures whether procedural or object-oriented. This design enables a developer to easily implement custom selection feedbackers and facilitate development of new ways for users to interact with a graphic.

Summary Of The Invention

It is therefore an object of the instant invention to: (1) provide a method to provide a developer-extensible method for supporting selection feedbackers and graphic interaction; and (2) provide object-oriented programming objects that support developer-extensible methods for supporting selection feedbackers and graphic interaction.

Brief Description Of The Drawings

The foregoing and other objects, aspects and advantages will be better understood from the following detailed description of a preferred embodiment of the invention with reference to the drawings. in which:

Figure 1a illustrates examples of selection feedback and graphic interaction;

Figure 1b is a block diagram of a computer system in accordance with a preferred embodiment;

Figures 2a and 2b provide examples of the class diagram notation;

Figure 3 illustrates the relationship of some of the major GrafEdit classes to the Application Framework;

Figure 4 illustrates the components in the graphic model in accordance with a preferred embodiment;

Figure 5 is an object diagram illustrating the relationship of the classes, methods, and interactions in the invention;

Figure 6 is a flow chart of the operation of the "first" method of a filter;

Figure 7 is a flow chart of the operation of the "next" method of a filter;

Figure 8 illustrates the layering concept of rendering canvas graphics and selection feedbackers;

Figure 9 is an object diagram illustrating the relationships between the classes, methods, and their interactions using the invention to render graphics with a selection feedback;

Figure 10 is an object diagram illustrating the relationships between the classes, methods, and their interactions using the invention to perform hit detection; and

Figure 11 is an object diagram illustrating the relationships between the classes, methods, and their interactions using the invention to support user interaction with graphics.

Diagramming Conventions

The following conventions are used in many of the figures. Refer to Figures 2a and 2b for the examples below. The "`xxx::yyy`" is a C++ construct known to those skilled in the art. The `xxx` part is a class name, the `yyy` part is the name of a method contained in the `xxx` class.

- Shadowed boxes 200 represent frameworks.
- Rounded boxes 201 represent classes, e.g. `TCanvasView`.
- Solid lines 202 represent method relationships and square boxes 203 represent the methods, e.g. `EnumerateGraphics` is a method of `TCanvasView`.
- Solid lines with arrows at their ends 204 represent method invocation, e.g. `TCanvasView::EnumerateGraphics` calls `TCanvasGraphicFilter::SetIterator`.
- Boxes drawn around several methods, (e.g., box 205 is drawn around `First`, `Last`, `Next` and `Previous` methods of `TCanvasGraphicReadIterator` 206) is used to simplify the diagram when all methods are used in a similar fashion. (E.g., `TCanvasGraphicFilter::First` 220 or `::Next` 221 can call any or all of these methods in the same way.)

- Solid lines with solid circles at their ends 207 represent containment relationships, e.g. `MCanvasRepresentation` 208 contains an ordered collection of `MCanvasGraphics` 209. A number along such a line 210 specifies the number of objects contained. When no number is shown, "1" is implied. When the letter "n" is shown, zero or more is implied.
- Dashed lines with circles at their ends 211 represent referential relationships. References imply that objects have access to objects and can invoke their methods, but do not contain them (i.e., do not manage storage of the objects, or own the object or are not responsible for destroying the objects). There are two such relationships depicted.
- A circle containing a "P" 212 denotes that an object of the given class is passed into the method as a parameter, e.g. a `TCanvasGraphicReadIterator` 217 is passed to `TCanvasGraphicFilter::SetIterator` 214 as a parameter.
- A circle containing an "R" 213 denotes a reference to an object of the given class that is contained in some other object. Therefore, a reference to the `TCanvasGraphicReadIterator` 217 is maintained by the `TCanvasGraphicFilter` 215.
- A dashed line with an arrow at the end represents object creation, e.g. `MCanvasRepresentation::CreateReadIterator` 216 creates an instance of `TCanvasGraphicReadIterator` 217.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT OF THE INVENTION

The invention is preferably practiced in the context of an operating system resident on a personal computer such as the IBM® PS/2® or Apple® Macintosh® computer. A representative hardware environment is depicted in Figure 1b, which illustrates a typical hardware configuration of a workstation 40 in accordance with the subject invention having a central processing unit 10, such as a conventional microprocessor, and a number of other units interconnected via a system bus 12. The workstation shown in Figure 1b includes: a Random Access Memory (RAM) 14; Read Only Memory (ROM) 16; an I/O adapter 18 for connecting peripheral devices such as disk units 20 or scanners 21 to the bus; a user interface adapter 22 for connecting a keyboard 24; a pointing device such as a mouse 26; a speaker 28; a microphone 32; and/or other user interface devices such as a touch screen device (not shown) to the bus; a communication adapter 34 for connecting the workstation to a data processing network 23; and a display adapter 36 for connecting the bus to a display device 38. The workstation has resident thereon an operating system 11 such as the Apple System/7® operating system.

In a preferred embodiment, the invention is implemented in the C++ programming language using object oriented programming techniques. As will be understood by those skilled in the art, Object-Oriented Programming (OOP) objects are software entities comprising

data structures and program logic that perform operations on the data. The program logic that operates on the object's data is commonly called a method of the object. Together, these elements enable objects to model virtually any real-world entity in terms of its characteristics, represented by its data elements, and its behavior, represented by its methods (data manipulation functions). In this way, objects can model concrete things like people and computers, and they can model abstract concepts like numbers or geometrical concepts. The invention is described within the GrafEdit context of application 8/146,631 referenced above. Relevant portions of GrafEdit are summarized below.

GrafEdit

GrafEdit works within a larger Application framework. As such, several of GrafEdit's classes are formal participants in the Application framework. In Figure 3 for example, `TCanvasView` 307 descends from `TView` 303. `TView` 303 introduces the `DrawContents` method 301. The Application framework 315 calls the `DrawContents` method 301 to request the view to draw itself. `TCanvasView` 307 overrides `TView`'s 303 `DrawContents` method 301 with `TCanvasView`'s 307 own version of `DrawContents` 305. Thus, `TCanvasView`'s 307 `DrawContents` method 305 is used to implement the Application framework's 315 request to draw.

Fundamental GrafEdit Classes

At the simplest level, GrafEdit has three main elements, "**canvas graphics**" that represents each graphical element in the canvas, a "**canvas representation**" that stores a collection of canvas graphics and a "**canvas view**" that renders the canvas graphics stored in the canvas representation. The canvas view rendering operation results with the canvas graphics being displayed to the user. The canvas view plays a central role in selection and interaction. (In application 8/146,631 these components were termed the "Component," the "Model," and the "Canvas" respectively.) These elements and their fundamental interrelationships are shown in Figure 4. The canvas representation 403 contains the canvas graphics 401. The canvas representation 403 also includes object methods (not shown) to manage the canvas graphics 401 in the representation 403. The canvas view 404 renders the canvas graphics 401 stored in the canvas representation 403. As the user interacts with the view 404, the view 404 manipulates the canvas representation 403 via commands as indicated by arrow 410. The representation 403 notifies client objects of any change made to the canvas representation 403. Upon receiving notification of the change in the canvas representation 403 these client objects may process the representation. Thus, when the canvas representation 403 changes, canvas view 404 is notified of the change and displays itself by creating or updating the display by causing the canvas graphic objects 401 to display themselves.

Canvas Graphics 401

Each graphical object that can be displayed is a canvas graphic (two of which are indicated by 401). The canvas representation 403 maintains a collection of canvas graphics 401. The canvas view 404 assumes the canvas graphic protocol for drawing, hit detection, selection and interaction. Canvas graphics 401 are derived from the `MGraphic` class (described in application 8/146,631 referenced above). The `MGraphic` class provides the basic protocol for two dimensional graphical operations. These protocols include those for transforming the graphic, finding the bounds of the graphic, and detecting whether the graphics intersects a given point.

The Canvas Representation 403

Each GrafEdit application has at least one canvas representation 403. The canvas representation stores and manages the canvas graphics 401 used by the application. The canvas representation 403 also provides several methods for adopting canvas graphics 401 into storage, removing canvas graphics 401 from storage, and finding canvas graphics 401 within storage. The canvas graphics 401 within the canvas representation 403 are ordered from front to back such that canvas graphic 406 is the front-most canvas graphic, followed by 407 and so forth until canvas graphic 408 — the back-most canvas graphic. When canvas view 404 draws the canvas representation 403, canvas graphics at the front of storage 406 are drawn on top of canvas graphics further back in storage 407, 408. The canvas representation also provides methods for altering the order of the stored canvas graphics. These methods include moving canvas graphics to the back, to the front, forward towards the front and backward towards the back. Finally, the canvas representation 403 provides facilities for iterating over the collection of canvas graphics 401 stored in the canvas representation 403.

The Canvas View 404

A canvas view 404 draws the contents of a canvas representation 403. A canvas view 404 also facilitates selection and interaction with canvas graphics 401 in the underlying canvas representation 403. Many canvas view 404 methods are invoked by the Application and GrafEdit frameworks. (One example involves interactors. Interactors are disclosed in application 08/295,442 referenced above.) However, some canvas view methods are directly called by developer-written classes. Developers implement the application's appearance and behavior by creating a subclass of `TCanvasView`, or a subclass of a `TCanvasView` subclass.

Enumerators, Filters, and Funnels

One of the more important functions of the canvas view 404 is that of performing an operation on all or some of the graphics in the representation As implemented in the canvas view class, the instant invention comprises an `EnumerateGraphics` method, added to the canvas view object, and two classes, `TCanvasGraphicFilter` and

TCanvasGraphicFunnel. To render the canvas graphics 401 stored in the canvas representation 403, the canvas view 404 must first create filter and funnel objects. The filter object is used to select and order which canvas graphics 401 are to be drawn. The funnel is used to process each of the canvas graphics 401 selected by the filter. In the example shown in Table 1, the canvas view 404 passes both the filter and funnel objects to the canvas view's EnumerateGraphics method. The EnumerateGraphics method passes the canvas graphics 401 furnished by the filter to the funnel for processing. Since developers can create custom filters and funnels, they can freely control which canvas graphics 401 are selected for processing, the order that the canvas graphics are processed and how the selected graphics are processed.

```
TCanvasTopSelectionDrawingFilter filter (aSelection);
TCanvasDrawingFunnel funnel (aGrafPort);
EnumerateGraphics (filter, funnel);
```

Table 1

The filter object is not limited to simply selecting canvas graphics from the canvas representation. The filter object also controls the sequence that canvas graphics are presented to the funnel. Thus, the filter can perform a sorting function. The filter can also introduce new graphics not contained within the canvas representation. This function is extremely important when implementing selection feedbackers. Selection feedbackers are temporary canvas graphics added to the display to indicate which graphics are selected and, optionally, to provide means for the user to interact with the graphics — through interactors. Selection feedbackers are not stored in the canvas representation 403. For example, the SRT feedbacker is a temporary canvas graphic that is rendered in front of the image of the selected graphic by the TCanvasTopSelectionHitDetectionFilter and the TCanvasTopSelectionDrawingFilter objects.

The EnumerateGraphics method (program logic) along with filter and funnel objects decouples the details of accessing the canvas representation data from iteration control and graphic processing. As a result, each of these elements is independently extensible without affecting the other two. For example, the same drawing code (encapsulated in a funnel object) can be reused independent of the underlying representation class and independent of the selection drawing strategy. This independently-extensible feature of the instant invention provides application developers with increased flexibility when implementing GUI based applications. Thus, the instant invention has utility.

Canvas filter and funnel objects furnish and process canvas graphics in the canvas view during drawing, hit detection, application initiation and similar processes. Filters select and sequence which graphics are to be processed. Funnels operate on each graphic furnished by the

filter. There are many possible funnel operations. A funnel may perform any operation that does not directly modify the canvas graphic returned by a filter. These operations include, among others, display, hit detection, graphic selection, sorting, and classifying operations.

In summary, the purpose of the `EnumerateGraphics` method is to bind a canvas view to a particular underlying storage scheme. The purpose of the filter object is to present canvas graphics from the representation to a funnel object. The funnel object operates on the presented canvas graphics to perform the task the developer implemented in the funnel object.

`EnumerateGraphics` Operation

Figure 5 shows the graphics enumeration behavior of the canvas view 404. This behavior is central to extensible selection feedback and interaction. Graphic enumeration is used in the canvas view to perform various read-only operations over graphics in the underlying canvas representation and other objects. Examples of these operations include, drawing, hit detection, interaction, and others. While enumeration is not used to directly modify graphics, enumeration can result in identifying graphics that will ultimately be changed by commands.

Table 2 shows a preferred embodiment of `EnumerateGraphics` written in C++. The client passes a filter object to `EnumerateGraphics`. `EnumerateGraphics` uses this filter object to select which graphics are included in the enumeration and the sequence that these graphics are presented to the funnel object. Thus, the filter uncouples the control of what is included in enumeration and the enumeration sequence, from the internal details of how the enumeration is implemented and the access protocol of the underlying canvas representation. `EnumerateGraphics` creates a `TCanvasReadIterator` object and gives this iterator to the client's filter object. `EnumerateGraphics` then uses the filter object to unidirectionally iterate over the canvas graphics contained in the canvas representation. The `EnumerateGraphics` implementation, shown in Table 2, uses `MCanvasRepresentation::CreateReadIterator` to return an iterator. If desired, developers may implement proprietary access methods instead of using the iterator created by the canvas representation. The returned iterator supports bi-directional, read-only iteration over the canvas graphics contained in the canvas representation. `EnumerateGraphics` does not directly use this iterator. Instead, `EnumerateGraphics` passes this iterator to the client-provided filter object that was passed by the client to `EnumerateGraphics`.

```
// COPYRIGHT TALIGENT, Inc.  1994
void
TStandardCanvasView::EnumerateGraphics (TCanvasGraphicFilter& filter,
                                        TCanvasGraphicFunnel& funnel) const
{
    TDocumentComponentReadEntry entry (GetModelReference());
    const TStandardCanvasModel *model = LookupCanvasModelForReading (entry);

    if ( model ) {
        TCanvasGraphicReadIterator *i =
            ((TStandardCanvasModel*)model)->CreateReadIterator ();

        if ( i ) {
            filter.SetIterator (i);
            const MCanvasGraphic *c = filter.First ();
            if ( c ) {
                while ( c ) {
                    if ( funnel.ProcessGraphic (*c) )
                        c = (MCanvasGraphic*)filter.Next ();
                    else
                        c = NIL;
                    }
                }
            delete i;
            }
        }
}
```

Table 2

Figure 5 graphically shows the operation of `EnumerateGraphics` 505. The canvas view 501 references the canvas representation 503. `EnumerateGraphics` 505 receives two parameters, a canvas graphic filter 507 and a canvas graphic funnel 509. `EnumerateGraphics` 505 calls the representation's `CreateReadIterator` 511 method to create a canvas graphic read iterator 513 and then passes the canvas graphic read iterator 513 to the filter's `SetIterator` 515 method. The filter 507 retains a reference to the iterator 513. Then `EnumerateGraphics` 505 calls the filter's `First` method 517. Subsequently, `EnumerateGraphics` 505 calls the filter's `Next` method 519 for so long as these methods continue to furnish (return) canvas graphics. If either of these methods returns `NIL`, `EnumerateGraphics` 505 has completely iterated over the potentially relevant canvas graphics. For each canvas graphic furnished by (returned from) the filter's `First` 517 and `Next` 519 methods, `EnumerateGraphics` passes the canvas graphic to the funnel's `ProcessGraphic` method 521 for processing.

Before calling the filter's `First` 517 and `Next` 519 methods, `EnumerateGraphics` 505 seeds the filter 507 with a canvas graphic read iterator 513. The read iterator 513 provides the filter 507 with access to the canvas graphics stored in the canvas representation 503. The filter 507 can call the iterator's 513 `First`, `Last`, `Next` and `Previous` methods 523 in various combinations to select which canvas graphics are returned and their sequence. For

example, if the filter 507 implements its `First` method 517 to call the iterator's 513 `Last` method 524 and if the filter 507 implements its `Next` method 519 to call the iterator's 513 `Previous` 525 method, the graphics will be parsed from back to front.

The filter 507 is capable of sophisticated operations (e.g., such as selecting canvas graphics in order of size or initially selecting all squares, followed by all lines, followed by other shapes). Another capability of the filter 507 is that it can introduce canvas graphics that do not exist in the canvas representation. For example, the filter 507 may return additional graphics to provide selection-handle and SRT feedbackers. Furthermore, the filter 507 may return a completely different canvas graphic from the one obtained from the canvas representation 503. This capability allows the filter 507 to return inverted or color shifted versions of user-selected graphics.

Those skilled in the art will recognize that filter 507 controls which canvas graphics are processed, the order that the canvas graphics are processed and that the filter can insert canvas graphics that are not present in the canvas representation to modify the displayed image from that contained in the canvas representation.

Filter Operation

Table 3 is illustrates a C++ embodiment of a filter that enumerates from back to front (i.e., the filter is used to provide the canvas graphics to a drawing funnel for rendering) and interjects selection feedback graphics on top of all selected graphics. The filter can use the canvas representation read iterator in various ways. For example, the iteration direction can be reversed by implementing the filter's `Next` method to call the canvas graphic read iterator's `Previous` method as shown in the `TCanvasTopSelectionDrawingFilter::Next` routine in Table 3. The filter can skip undesired graphics by calling the canvas graphic read iterator's `Next` or `Previous` methods multiple times before returning. The filter can also introduce and return graphics that it creates in place of, or in addition to, those that the canvas graphic read iterator returns. Thus, the graphics processed by the funnel do not necessarily have a one-to-one correspondence with the canvas graphics stored in the canvas representation. For example, selection feedback graphics are temporary and not contained in the canvas representation.

```
// COPYRIGHT TALIGENT, Inc.  1994
class TCanvasTopSelectionDrawingFilter : public TCanvasSelectionFilter
{
    public:
        TCanvasTopSelectionDrawingFilter (
                                        const MCanvasSelection* referenceSelection);
        virtual ~TCanvasTopSelectionDrawingFilter ();
        // Iteration from back to front
        virtual const MCanvasGraphic*       First ();
        virtual const MCanvasGraphic*       Next ();
    private:
        void*                               fExtension;
        const MCanvasSelection*             fSelection;         // not owned
        bool                                fSelectionPass;
        MCanvasGraphic*                     fCurrentFeedbacker;  // not owned
};

TCanvasTopSelectionDrawingFilter::TCanvasTopSelectionDrawingFilter (
                                        const MCanvasSelection* selection) :
    TCanvasSelectionFilter(),
    fSelection (selection),
    fSelectionPass (false),
    fCurrentFeedbacker (NIL) {}

TCanvasTopSelectionDrawingFilter::~TCanvasTopSelectionDrawingFilter () {}

const MCanvasGraphic*
TCanvasTopSelectionDrawingFilter::First ()
{
    TCanvasGraphicReadIterator *i = GetIterator ();
    const MCanvasGraphic* first = NIL;
    if ( i )
        first = i->Last ();
    return first;
}

const MCanvasGraphic*
TCanvasTopSelectionDrawingFilter::Next ()
{
    TCanvasGraphicReadIterator *i = GetIterator ();
    const MCanvasGraphic* next = NIL;

    if ( i ) {
        next = i->Previous ();
        if ( next == NIL && !fSelectionPass && fSelection != NIL) {
            fSelectionPass = true;
            next = i->Last ();
            }
        if ( fSelectionPass ) {
            while (next != NIL && !fSelection->IsGraphicSelected(*next))
                next = i->Previous ();
            if ( next != NIL ) {
                fCurrentFeedbacker = GetGraphicFeedbacker (*next);
                if (!fCurrentFeedbacker)
                    fCurrentFeedbacker = GetCanvasFeedbacker (*next);
                next = fCurrentFeedbacker;
                }
            }
        }
    return next;
}
```

Table 3

The concepts in Table 3 are illustrated by Figures 6 and 7. These figures have been simplified for clarity but provide a conceptual overview of the program logic in Table 3. Figure 6 illustrates the filter object's `first` method. The initialization block 601 represents the initialization functions for the `first` method. Initialization consists of obtaining an iterator and initializing the variable `first` to `NIL`. After initialization, if the iterator was not obtained during the initialization block 601, the method simply returns `first` (which will contain `NIL`) by returning via the return block 604. If an iterator was obtained during initialization, execution continues and the method returns `iterator->Last` (the back-most canvas graphic in the canvas representation) through the return block 604.

Figure 7 illustrates the filter object's `next` method. This method is entered via the initialization block 700. The first-pass-decision block 701 detects if the first pass is complete (i.e., that all canvas graphics have been enumerated). If the first pass is not complete, the method returns the next canvas graphics (obtained from `iterator->Previous`) and exits via the return block 702. If the first pass is complete, execution passes to decision block 703. If this is the first entry into the second pass, execution passes to block 705 where `candidategraphic` is set to `iterator->Last` (hence obtaining the back-most graphic from the canvas representation) and execution passes to decision block 704, otherwise execution passes directly to decision block 704. At decision block 704 if `candidategraphic` contains `NIL` (indicating that iteration is complete) the method returns `NIL` through block 706. If `candidategraphic` does not contain `NIL`, execution passes to decision block 707. If the graphic contained in `candidategraphic` is not selected, execution continues to block 708. Block 708 sets `candidategraphic` to the next canvas graphic toward the front of the representation. Execution then loops again to decision block 704. However, at decision block 707 if `candidategraphic` contained a canvas graphic that was selected, execution continues to block 709. Some canvas graphics can create graphic-specific selection feedbackers. Decision block 709 detects if the graphic in `candidategraphic` includes this capability. If so, execution advances to block 710 which creates and returns the graphic specific selection feedbacker. If the graphic in `candidategraphic` can not create a graphic-specific selection feedbacker, execution advances to block 711 which creates and returns the default selection feedbacker.

Funnel Operation

Those skilled in the art will recognize that the funnel object processes the canvas graphics provided by the enumerator (returned by the filter) according to the program logic contained in the funnel object (not shown). A drawing funnel object draws each graphic presented by a filter. A hit detection funnel object performs hit detection of a given coordinate against each canvas

graphic presented by the filter and can determine the front-most graphic that contains the coordinate. Canvas graphic funnel objects decouple how each enumerated canvas graphic is processed from the internal details of how each canvas graphic is enumerated. Further, Canvas graphic funnels decouple how the canvas graphic is processed from the access protocol of the underlying canvas representation.

Canvas graphic funnels are passive iterators that process graphics enumerated in `TCanvasView::EnumerateGraphics` 505. Clients create and pass a funnel object 509 to `EnumerateGraphics` 505. `EnumerateGraphics` 505 calls the funnel object's `ProcessGraphic` method 521 for each graphic returned by the filter object 507 in the order the filter object 507 provides them. Developers create funnel subclasses and override the `ProcessGraphic` method 521 to provide custom processing for the enumerated canvas graphic objects (e.g., drawing each graphic). An example of this is shown in Figure 9 (described in detail in the Drawing Graphics description below). In Figure 9, a client creates and passes a `TCanvasDrawingFunnel` object 908 (corresponding to funnel object 509) to `EnumerateGraphics` 906 (corresponding to the method at 505) to render the canvas graphics passed by the filter object 507, 907. In this case, `TCanvasDrawingFunnel` 908 is constructed from a port object 903. `TCanvasDrawingFunnel` 908 uses the port 903 to render the canvas graphics. By creating various types of ports, developer can affect the drawing in various ways (e.g., such as to draw all graphics with a scale factor of 10x or with a red frame color).

The architecture of the instant invention requires that `ProcessGraphic` return `FALSE` to pre-terminate the enumeration. This is demonstrated in a preferred embodiment of `EnumerateGraphics` 505 as shown in Table 2. For example, a hit detection funnel object would return `FALSE` upon reaching the canvas graphic object that intersected the pointing device to avoid looking at other canvas graphic objects.

Other funnel objects can use the canvas graphic in `ProcessGraphics` to create different objects that exist beyond the scope of `ProcessGraphics`. For example, while `TCanvasDrawingFunnel` 908 draws the graphic into a port, `TCanvasInteractionFunnel` 1104 calls the graphic to create an interactor.

Selections

The `TCanvasSelection` class is used to represent a collection of zero or more canvas graphics that are stored in the canvas representation. Canvas graphics within this collection are the target of some operation (e.g., a command). GrafEdit commands are bound to a canvas selection object. Thus, the canvas selection object specifies which canvas graphics in the representation are to be affected by the command. A special selection is the "current selection". The current selection contains the currently selected canvas graphics. The application maintains a single canvas selection for this purpose. This canvas selection is accessed by

canvas view methods, `AdoptCurrentSelection`, `SetCurrentSelection`, and `CopyCurrentSelection`. The canvas selection object contains methods to make a canvas graphic selected (`SelectGraphic`), and to determine which graphics are selected (`IsGraphicSelected`).

As discussed below, in the preferred embodiments, the view's `DrawContents` method calls `DrawGraphics` to render the canvas graphics that appear in front of any background and behind any operation feedback. This is a layer concept. First the background layer is rendered, then the graphics layer, and finally the feedback layer. This feedback layer is not associated with selection feedbackers. Feedbackers are canvas graphics drawn on top of canvas graphics that are in the canvas representation and the current selection. The feedback layer is a graphics layer used to provide manipulation feedback to a user who is modifying a graphic. (e.g., rubberbanding.)

`DrawGraphics` renders the graphics layer. In a preferred embodiment, `DrawGraphics` makes two passes over the canvas representation. The first pass renders the canvas graphics in the canvas representation. The second pass draws selection feedbacker graphics on top of the canvas graphics within the "current selection". Other possible embodiments can be implemented by the application developer as required. Figure 8 illustrates the operation of the multiple pass embodiment. The ovals 801, 802 and 803 are first drawn in front of the background 804. Only a portion of the background 804 is shown. Assume ovals 801 and 802 are selected. Thus, these canvas graphics are also contained in the current selection object. Oval 801 uses the default canvas selection feedbacker 805, and oval 802 includes a special selection feedbacker 806 (a handle feedbacker). Note that the dashed lines 808 containing the four small squares and the label "806" are not part of the feedbacker, but simply associate the four separated small squares with their label. As described above, selection feedbacker graphics are added to the rendered image after the canvas graphics are drawn. Thus, feedbacker images are superimposed on the canvas graphic image creating the complete rendered image 807. Any interactive feedback graphics that may be required are then rendered in the feedback layer in front of the graphics layer. An example of an interactive feedback graphic is seen when a user selects multiple graphics by dragging the pointing device. The interactive feedback graphic is the rubberband-rectangle that surrounds the selected graphics.

Examples of Preferred Embodiments in GrafEdit

The following describes selected preferred embodiments of the instant invention. These embodiments illustrate how to use the invention to perform drawing, hit detection and user interaction with canvas graphics. The invention enables application or program developers to implement their own customized strategies for user/graphic interactions.

Drawing Graphics

Figure 9 shows how GrafEdit uses the invention to draw graphics. The Framework 901 calls the view's 904 `DrawContents` method 902, passing a graf port object 903. Anything drawn into the graf port object 903 will appear on the screen, relative to and clipped by the application's window. `DrawContents` 902 calls three methods: `DrawBackground` (not shown), `DrawGraphics` 905, and `DrawFeedback` (not shown). `DrawBackground` defaults to draw a solid background. However, a developer can customize `DrawBackground` to draw anything that should appear behind all other graphics. `DrawGraphics` 905 draws the graphics in the representation and any selection feedbackers. `DrawFeedback` draws a temporary feedback layer in front of all graphics. Feedback is associated with interaction (e.g. rubberbands that appear while drawing new graphics).

`DrawGraphics` 905 uses `EnumerateGraphics` 906 to select and render the canvas graphics. As described above, `DrawGraphics` 905 passes filter 907 and funnel 908 objects to `EnumerateGraphics` 906. In this embodiment the default filter is a `TCanvasTopSelectionDrawingFilter` object 907 and the default funnel is a `TCanvasDrawingFunnel` object 908. Developers can subclass these classes to implement customized drawing behavior. `TCanvasTopSelectionDrawingFilter` 907 is constructed from the `MCanvasSelection` 910 object that `DrawGraphics` 905 created by calling `CopyCurrentSelection` 909. `TCanvasDrawingFunnel` 908 is constructed from the graf port object 903 passed to `DrawContents` 902 by the framework 901. Once constructed, `TCanvasDrawingFunnel` 908 is passed to `EnumerateGraphics` 906. In addition, `TCanvasDrawingFunnel` 908 references the graf port object 903 and renders each canvas graphic passed to it during enumeration into the graf port object 903.

`TCanvasTopSelectionDrawingFilter` 907 selects graphics from the representation from back to front (the standard drawing order so that front graphics are drawn over back graphics). During enumeration, `TCanvasTopSelectionDrawingFilter` 907 makes two passes over the canvas graphics in the canvas representation. On the first pass, the filter 907 returns the actual canvas graphics. These canvas graphics are processed and drawn before the selection feedbackers are processed (hence, displayed behind the selection feedbackers). On the second pass the filter 907 uses the selection 910 to determine which graphics are selected. For each selected graphic the filter 907 returns a selection feedbacker 912. Thus, the feedbackers are drawn on top of the canvas graphics contained in the canvas representation.

The selection feedback graphics can be created in one of two ways. First, the filter can call the selected canvas graphic's `CreateFeedbacker` method, giving the graphic an opportunity to supply a graphic-specific selection feedbacker. If the graphic returns a selection feedbacker (the return was not `NIL`) this selection feedbacker is drawn. Second, if the graphic returns `NIL` then the filter 907 uses a default selection feedbacker.

This architecture allows the developer to extend selection feedback and drawing facilities. The developer simply overrides `DrawGraphics` 905 and constructs and passes specialized filters and funnels to `EnumerateGraphics` 906. For example, to implement a folder that shows selection of documents by color shifting icons the developer might implement a `TCanvasGraphicColorShiftingDrawingFilter` (not shown) that returns color shifted graphics in place of selected graphics in the representation. Color shifted graphics could be implemented as wrappers around the real graphics that implement the `MCanvasGraphic::Draw` method to change the graf port for color shifting and then call the original canvas graphic's `Draw` method.

Hit Detection

Hit detection determines which displayed graphic intersects the pointing device. Like the graphics drawing features of GrafEdit, hit detection also uses the invention. Hit detection is shown in Figure 10. The `TCanvasView::Hit` method 1001 calls `EnumerateGraphics` 1002 with an appropriate filter and funnel. A hit occurs when the top-most graphic intersects a specified point (often the point is specified by the pointing device). Therefore the `TCanvasFrontToBackFilter` object 1003 selects canvas graphics from front to back in the canvas representation. The `TCanvasFrontToBackFilter` object 1003 does not use the "current selection". This is because hit detection is limited to canvas graphics stored in the canvas representation and does not need to consider selection feedbackers. (However, an application developer could change this operation by changing the filter.) The `TCanvasHitDetectionFunnel` object 1004 accepts each graphic passed to its `ProcessGraphics` method 1005. It then performs an intersection test to determine whether the specified point is within the graphic. If so, it remembers the graphic and returns `FALSE` from `ProcessGraphic` 1005. As mentioned above, `TCanvasGraphicFunnel::ProcessGraphic` returns `TRUE` to condition `EnumerateGraphics` 1002 (that calls it) to continue enumeration, or returns `FALSE` to condition `EnumerateGraphics` 1002 to terminate enumeration. Thus, if the purpose of the funnel is to look for a graphic that meets specified criteria, it can terminate enumeration (the process of iterating) once the graphic has been found. Once `EnumerateGraphics` 1002 returns to `TCanvasView::Hit` 1001, `TCanvasView::Hit` 1001 calls the funnel's `GetHitGraphicID` 1006 method to identify which canvas graphic was hit by the pointing device, if any.

Graphic Interaction

The invention can be used to implement user interaction with a graphic. The main difference between the graphic interaction embodiment and the previous embodiments is in the filter and funnel. Interaction begins when the cursor tools framework 1101 calls a

TCanvasView 1102 method to create and return a tool interactor. An interactor is an object that supplies information used to control and/or handle interaction (e.g., such as what to do while the pointer device button is held down, what to do when the pointer device is incrementally moved, and what to do when the pointer device button is released). The tool interactor is started by, and becomes a standard part of, the cursor tools architecture. The tool interactor handles pointer events and executes commands against the tool handler to accomplish the interactor's purpose. Interactors are described in application 08/295,442 referenced above.

The invention is related to how the view creates the interactor. The canvas view's 1102 CreateToolInteractor method 1109 creates a filter 1105 and funnel 1104 and passes them to EnumerateGraphics 1112. The funnel 1104 is constructed from the point 1120 that was passed to CreateToolInteractor 1109 from the framework.

During enumeration, TCanvasTopSelectionHitDetectionFilter 1105 makes two passes over the canvas graphics in the canvas representation 1114. During the first pass the filter 1105 considers only selected canvas graphics (i.e., in a supplied canvas selection object 1116) enumerating from front-to-back. For each selected canvas graphic, the filter 1105 creates a corresponding selection feedbacker by calling the canvas graphic's CreateFeedbacker method 1106. The filter 1105 returns this selection feedbacker to EnumerateGraphics 1112. During the second pass the filter 1105 returns canvas graphics in the canvas representation 1114 from front-to-back. Both the selection feedbackers and the graphics from the canvas representation are canvas graphics. The funnel 1104 will process them the same.

Each canvas graphic and selection feedbacker furnished by the filter 1105 is passed to the funnel's ProcessGraphic method 1118. For each graphic passed to the funnel 1104, the funnel's ProcessGraphic method 1118 first performs hit detection to determine if the graphic is hit by the point 1120 that was passed into CreateToolInteractor 1109 (because the funnel 1104 was constructed by CreateToolInteractor 1109 and was passed a reference to the point 1120 at this time). If the point 1120 does not intersect the canvas graphic (e.g., there was not a hit), the funnel 1104 does nothing with the passed canvas graphic and simply returns TRUE to EnumerateGraphics 1112 to continue enumeration. However, if a hit is detected the funnel 1104 calls the hit graphic's CreateInteractor method 1108 passing the point 1120. The graphic can support multiple types of interactions, in which case the graphic determines which area of the graphic was intersected by the point 1120 and returns the appropriate interactor. Note that design allows interaction to be location dependent within the graphic. This allows graphics such as the SRT selection feedbacker to supply special interactors (to support Scale, Rotation, and Translate interactions) dependent on where the point 1120 intersects the selection graphic. If the graphic does not specify a special interactor at the given point 1120 the graphic returns NIL. The funnel 1104 retains the returned value for later use in the funnel's OrphanInteractor method 1110.

After EnumerateGraphics 1112 returns, CreateToolInteractor 1109 calls the funnel's OrphanInteractor method 1110 to extract the interactor retained by the funnel 1104 during enumeration. If OrphanInteractor 1110 returns NIL, CreateToolInteractor 1109 creates a default interactor. In either case the interactor (either the default or the one saved by the funnel 1104) is returned to the cursor tools framework 1101. The cursor tools framework 1101 starts the interactor to begin the embodied interaction.

While the invention has been described in terms of a series of preferred embodiments, those skilled in the art will recognize that the invention can be practiced, with modification, in other and different hardware and software environments within the spirit and scope of the appended claims.

CLAIMS

Having thus described our invention, what we claim as new, and desire to secure by Letters Patent is:

1. A method,
    for use with a computer,
  for providing selection feedback and graphic interaction,
  said computer having
    an attached display,
    a pointing device,
    modeling program logic for
      modeling a plurality of graphical data structures,
    rendering program logic for
      rendering said graphical data structures on said display;
    selection program logic for
      selecting said graphical data structures on said display,
    modification program logic for
      modifying said graphical data structures from said display;
  said method comprising:

(a) specifying a filter;

(b) specifying a funnel; and

(c) an enumeration step for iterating over said plurality of graphical data structures, said filter furnishing a relevant graphical data structure and said funnel processing said relevant graphical data structure on each enumeration.

2. The method of claim 1 including: terminating said enumeration step responsive to said funnel.

3. The method of claim 1 wherein: said funnel processing includes rendering said relevant graphical data structure onto said attached display.

4. The method of claim 1 wherein: said funnel processing includes detecting a hit on said relevant graphical data structure by a point.

5. The method of claim 1 wherein: said funnel processing includes creating an interactor object for user interaction with said relevant graphical data structure.

6. The method of claim 1 wherein: said filter processing includes furnishing a first relevant graphical data structure from said plurality of graphical data structures on a first iteration, and a second relevant graphical data structure from said plurality of graphical data structures on a second iteration.

7. The method of claim 1 wherein: said filter processing includes furnishing a feedbacker relevant graphical data structure said feedbacker relevant graphical data structure not included within said plurality of graphical data structures.

8. The method of claim 1 wherein: said filter processing includes furnishing a feedbacker relevant graphical data structure responsive to one of said plurality of graphical data structures.

9. The method of claim 1 wherein: said filter processing includes furnishing said relevant graphical data structure dependent upon data included in each of said plurality of graphical data structures.

10. The method of claim 1 wherein: said graphical data structure is contained within an object-oriented programming object.

11. Software, as implemented on a computer, to provide
selection feedback and graphic interaction capabilities in said computer
said computer having
an attached display,
a pointing device,
modeling program logic for
modeling a plurality of graphical data structures,
rendering program logic for
rendering said graphical data structures on said display;
selection program logic for
selecting said graphical data structures on said display,
modification program logic for
modifying said graphical data structures on said display;
said software comprising:

(a) a filter routine to access said plurality of graphical data structures and return a relevant graphical data structure;

(b) a funnel routine to process said relevant graphical data structure; and

(c) an enumeration routine to iterate over said plurality of graphical data structures by repeatedly evoking both said filter routine and said funnel routine; said enumeration routine passing said relevant graphical data structure, returned from said filter, to said funnel routine for processing.

12. The software of claim 11 wherein: said funnel routine directs said enumeration routine to terminate iteration.

13. The software of claim 11 wherein: said funnel routine renders said relevant graphical data structure onto said attached display.

14. The software of claim 11 wherein: said funnel routine detects a hit on said relevant graphical data structure by a point.

15. The software of claim 11 wherein: said funnel routine creates an interactor object for user interaction with said graphical data structure.

16. The software of claim 11 wherein: said filter routine returns a first relevant graphical data structure from said plurality of graphical data structures on a first iteration, and said filter routine returns a second relevant graphical data structure from said plurality of graphical data structures on a second iteration.

17. The software of claim 11 wherein: said filter routine returns a feedbacker relevant graphical data structure, said feedbacker relevant graphical data structure not included within said plurality of graphical data structures.

18. The software of claim 11 wherein: said filter routine returns a feedbacker relevant graphical data structure responsive to one of said plurality of graphical data structures.

19. The software of claim 11 wherein: said filter routine returns said relevant graphical data structure dependent upon data included in each of said plurality of graphical data structures.

20. The software of claim 11 wherein said graphical data structure is contained within an object-oriented programming object.

21. The software of claim 11 wherein: said filter routine returns said relevant graphical data structure from said plurality of graphical data structures.

22. An object-oriented graphical framework for implementation on a computer,
said framework comprising
    a first plurality of canvas graphic objects,
    a canvas representation object,
    and a canvas view object,
said representation object comprising
    a second plurality of canvas graphic objects and
said view object comprising
    means for rendering said first plurality of graphic objects using said framework,
said second plurality of canvas graphic objects
    being a subset of said first plurality of canvas graphic objects;
said view object comprising:

(a) a filter object for
furnishing a relevant canvas graphic object for processing,
said relevant canvas graphic object
    selected from said first plurality of canvas graphic objects;

(b) a funnel object that processes said relevant canvas graphic object using said framework; and

(c) an enumeration object-method for
    iterating over said second plurality of canvas graphic objects
        in said representation object,
said filter object and said funnel object passed to said enumeration object-method,
said enumeration object-method obtaining said relevant canvas graphic object
    from said filter object and
passing said relevant canvas graphic object to said funnel object for processing.

23. The object-oriented graphical framework of claim 22 wherein: said enumeration object-method terminates enumeration responsive to said funnel object processing.

24. The object-oriented graphical framework of claim 22 wherein: said computer further comprises a display and said funnel object renders said relevant canvas graphic object onto said display.

25. The object-oriented graphical framework of claim 22 wherein: said computer further comprises a pointing device and a display, and said funnel object detects a hit on said relevant canvas graphic object by a point.

26. The object-oriented graphical framework of claim 22 wherein: said filter object furnishes a first relevant canvas graphic object from said first plurality of graphical objects on a first iteration, and a second relevant canvas graphic object from said first plurality of graphical objects on a second iteration.

27. The object-oriented graphical framework of claim 22 wherein: said filter object furnishes a feedbacker relevant canvas graphic object, said feedbacker relevant canvas graphic object not within said second plurality of canvas objects.

28. The object-oriented graphical framework of claim 22 wherein: said filter object furnishes said relevant canvas graphic object, said relevant canvas graphic object responsive to one of said first plurality of graphical objects.

29. The object-oriented graphical framework of claim 22 wherein: said filter object furnishes said relevant graphical object dependent upon data included in each of said first plurality of graphical objects.

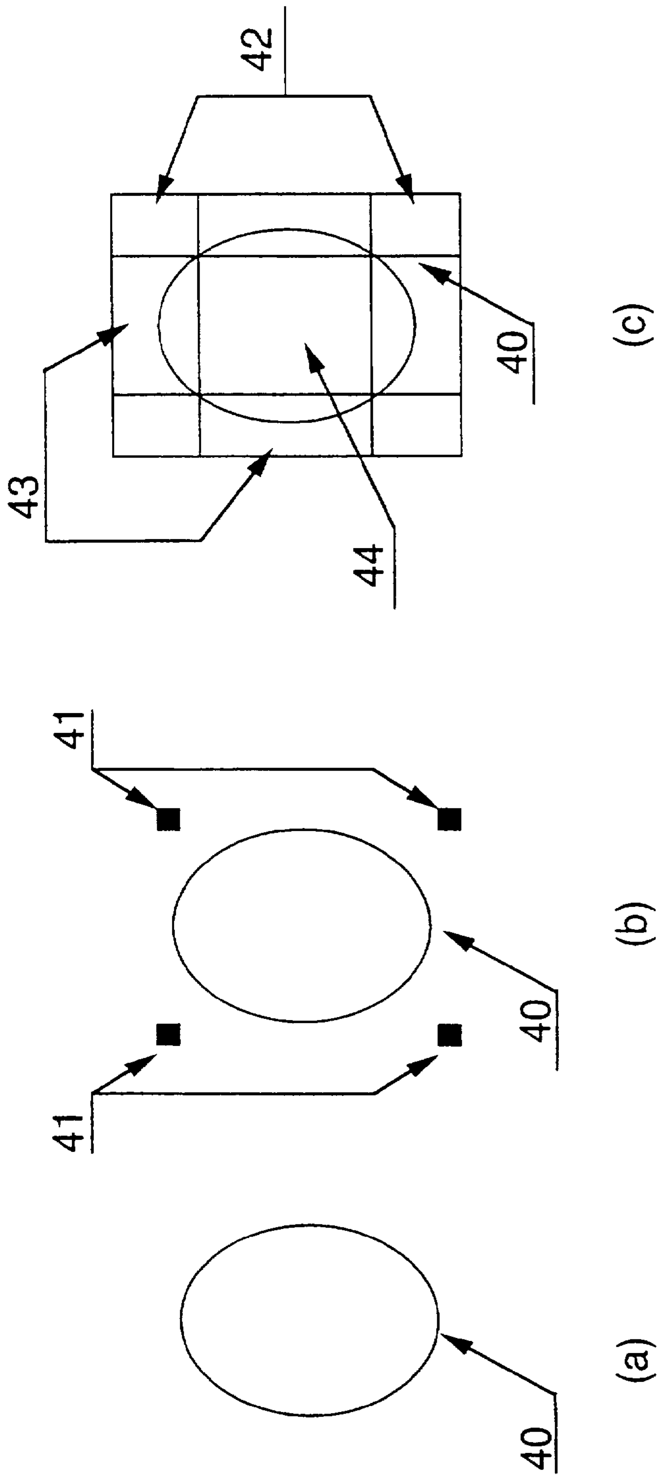


Fig. 1a

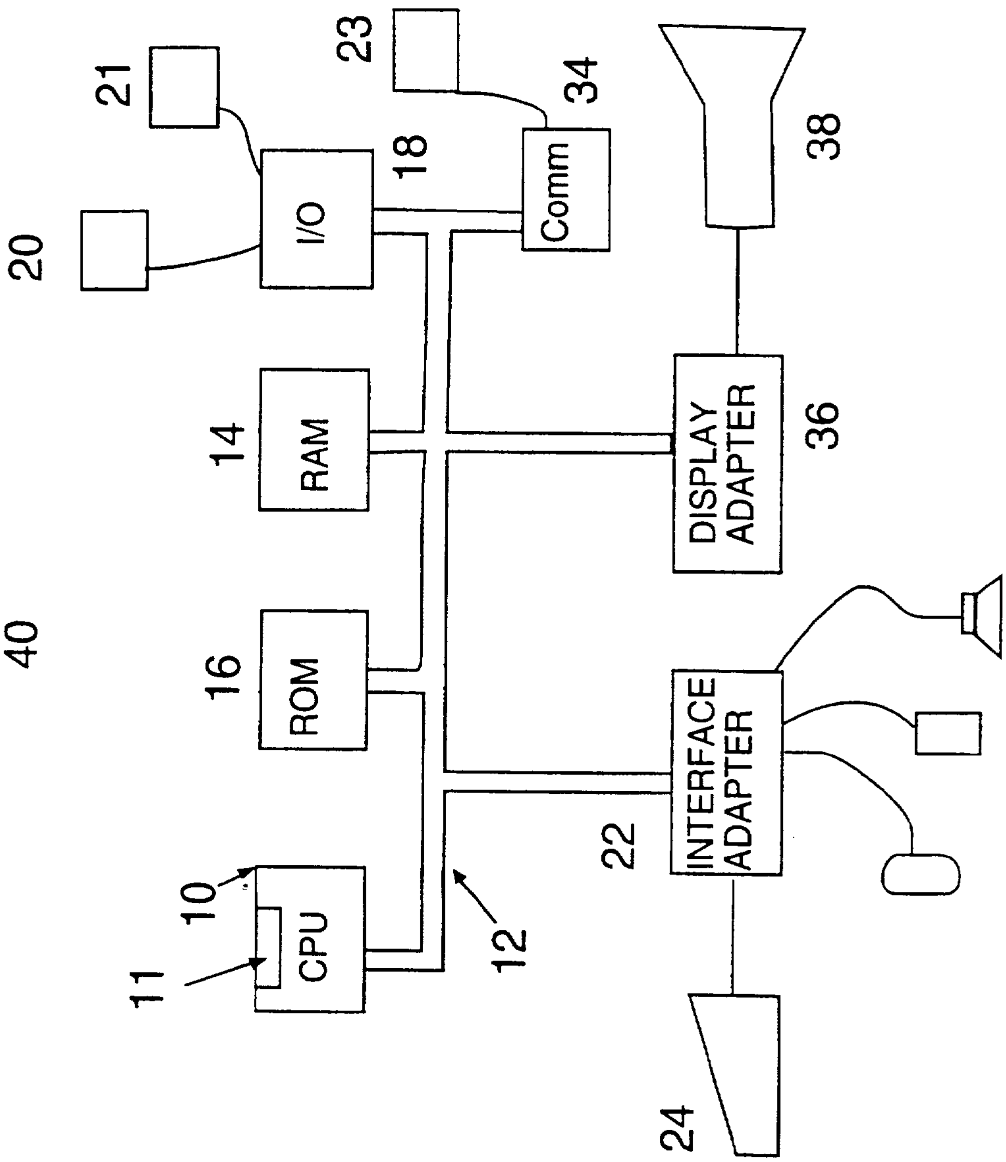

40
CPU
11
10
12
ROM
16
RAM
14
I/O
18
20
21
Comm
34
23
22
INTERFACE ADAPTER
DISPLAY ADAPTER
36
38
24
26
28
32

Fig. 1b

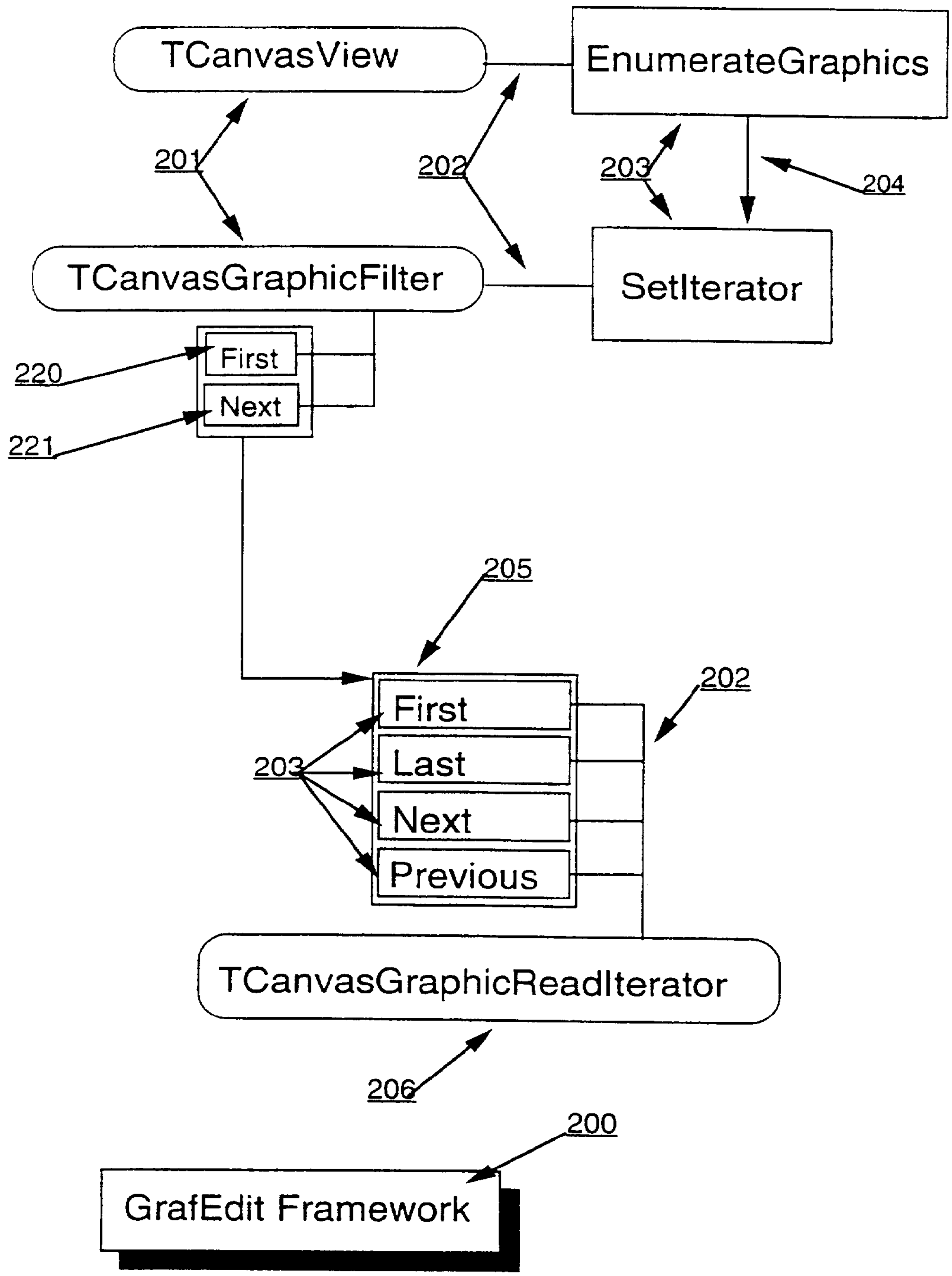

TCanvasView
EnumerateGraphics
201
202
203
204
TCanvasGraphicFilter
SetIterator
First
Next
220
221
205
202
First
Last
Next
Previous
203
TCanvasGraphicReadIterator
206
200
GrafEdit Framework

Fig. 2a

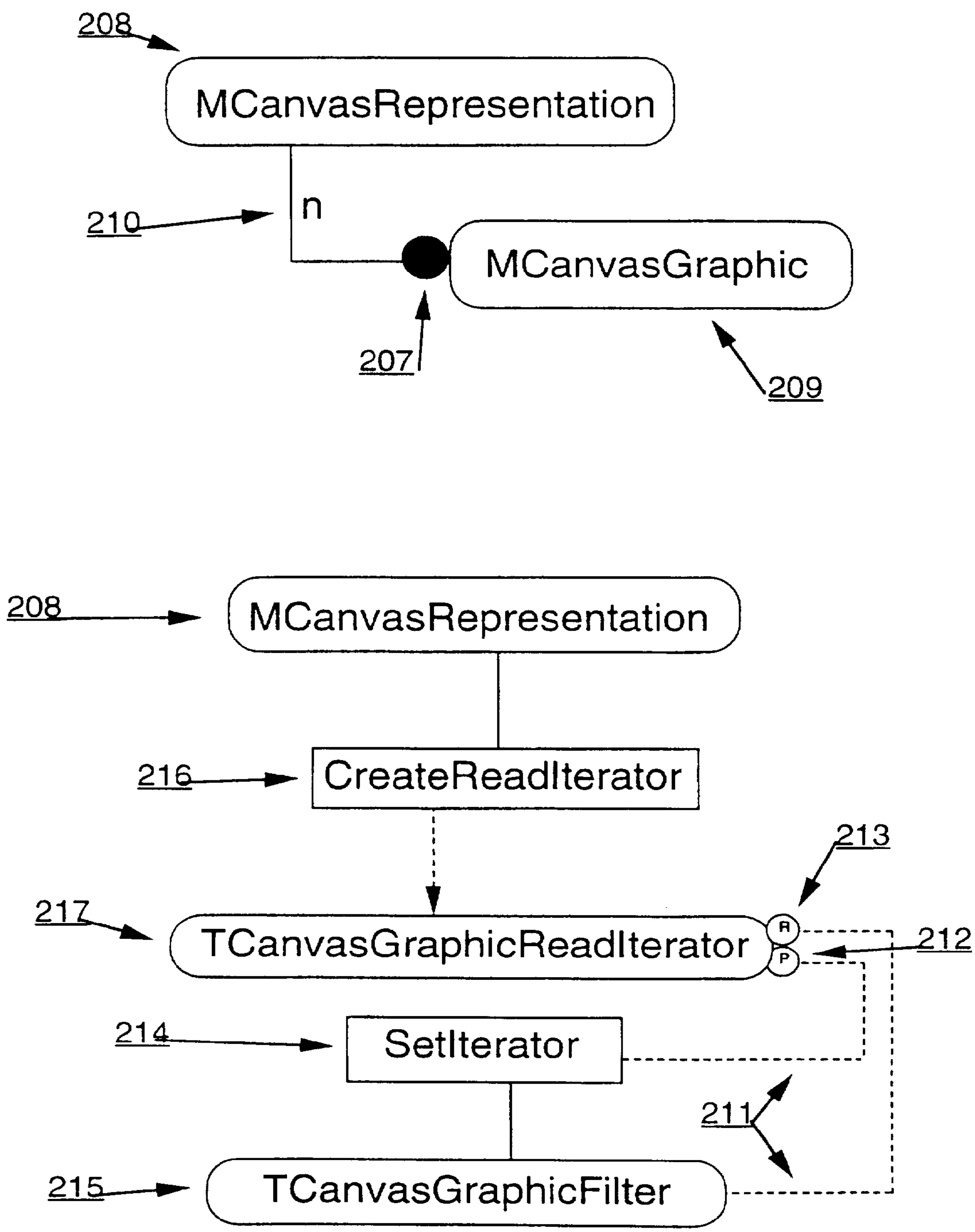
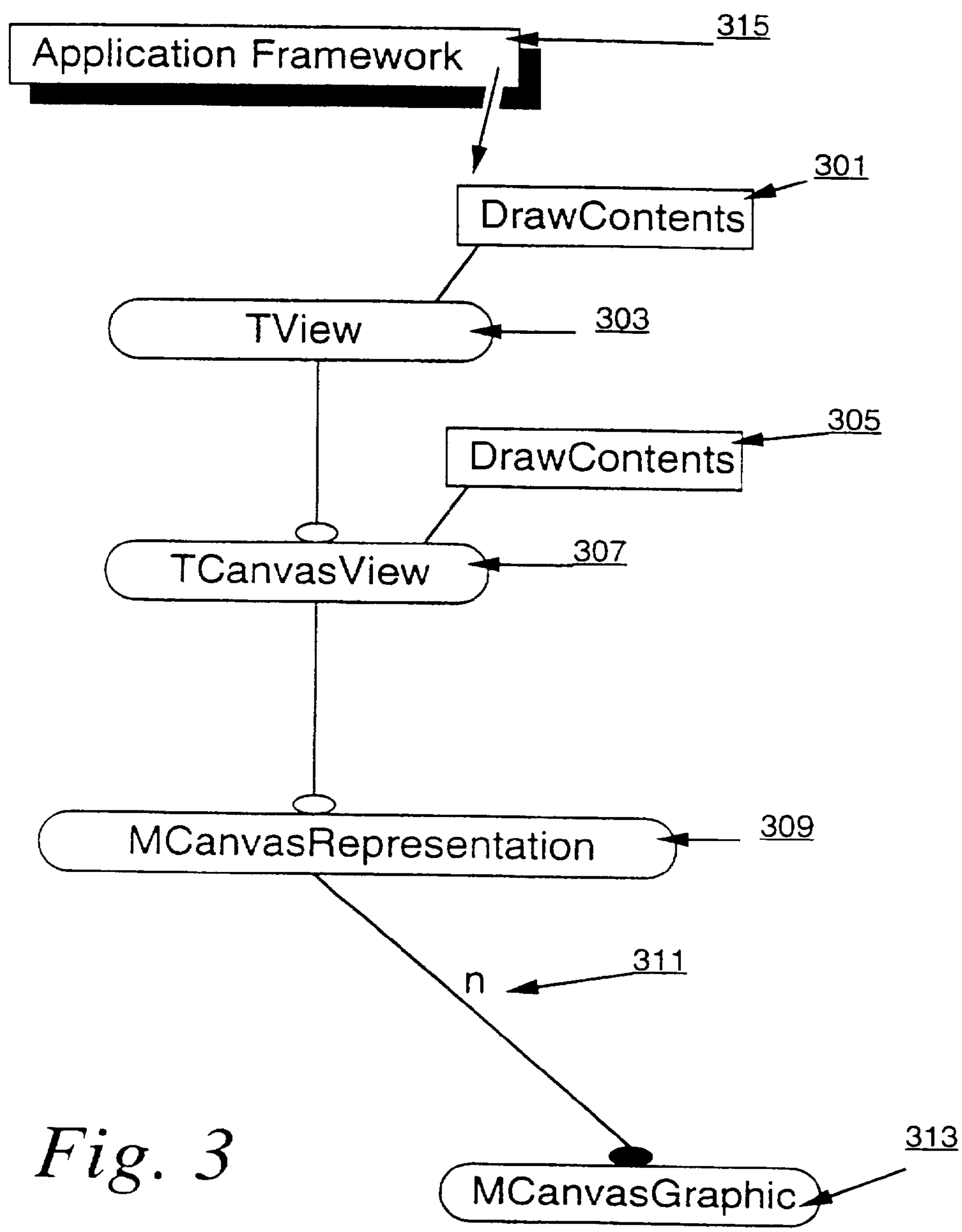

208
MCanvasRepresentation
n
210
MCanvasGraphic
207
209
208
MCanvasRepresentation
216
CreateReadIterator
213
217
TCanvasGraphicReadIterator
R
P
212
214
SetIterator
211
215
TCanvasGraphicFilter

Fig. 2b



Application Framework
315
DrawContents
301
TView
303
DrawContents
305
TCanvasView
307
MCanvasRepresentation
309
n
311
MCanvasGraphic
313

Fig. 3

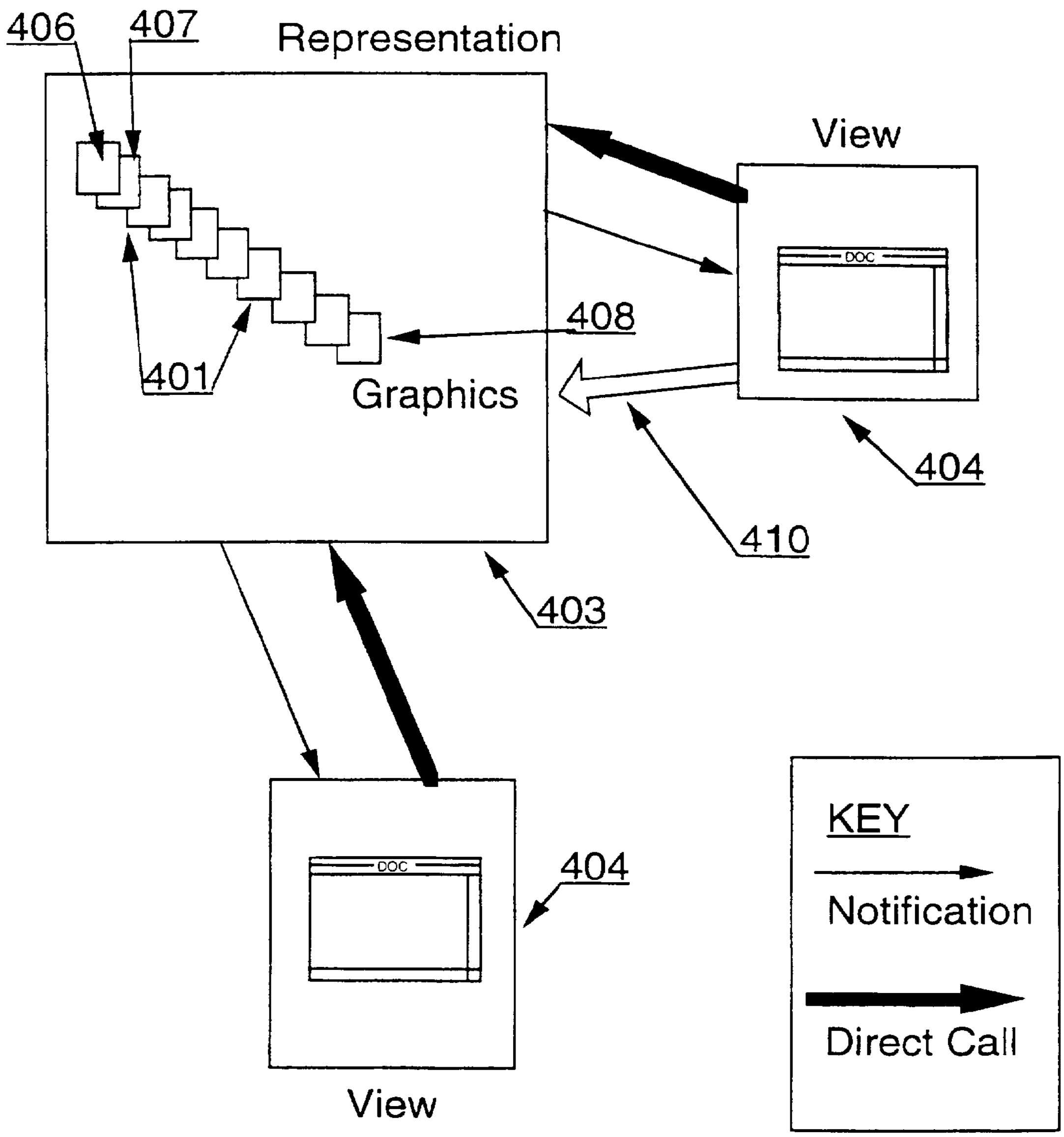
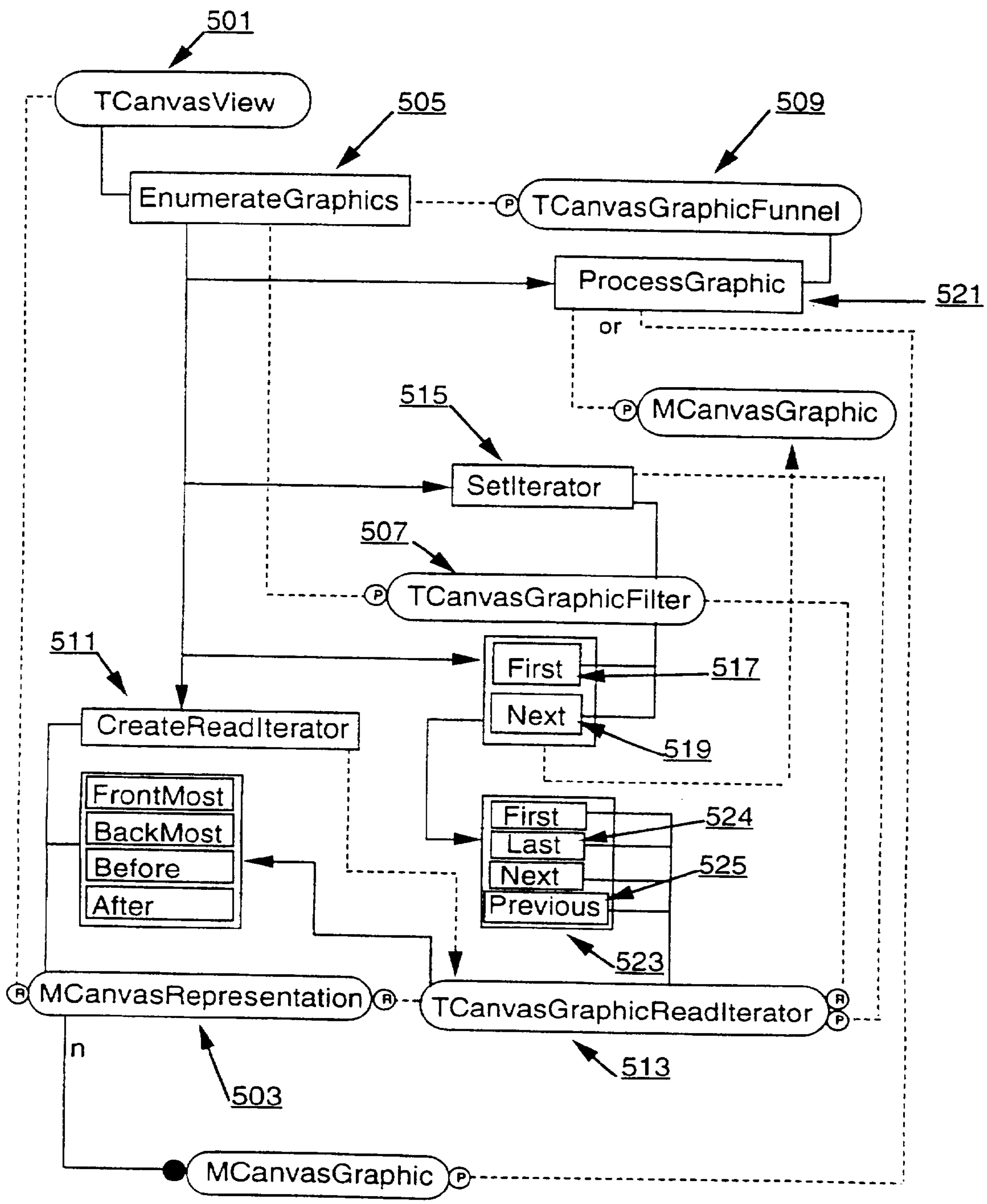

406
407
Representation
View
DOC
408
401
Graphics
404
410
403
DOC
404
View
KEY
Notification
Direct Call

Fig. 4



501
TCanvasView
505
EnumerateGraphics
509
TCanvasGraphicFunnel
ProcessGraphic
521
or
MCanvasGraphic
515
SetIterator
507
TCanvasGraphicFilter
511
First
517
Next
519
CreateReadIterator
FrontMost
BackMost
Before
After
First
524
Last
Next
525
Previous
523
MCanvasRepresentation
TCanvasGraphicReadIterator
n
503
513
MCanvasGraphic

Fig. 5

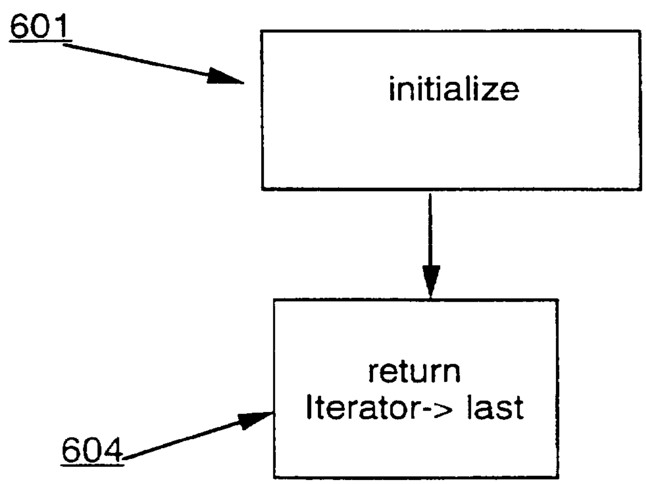


Fig. 6

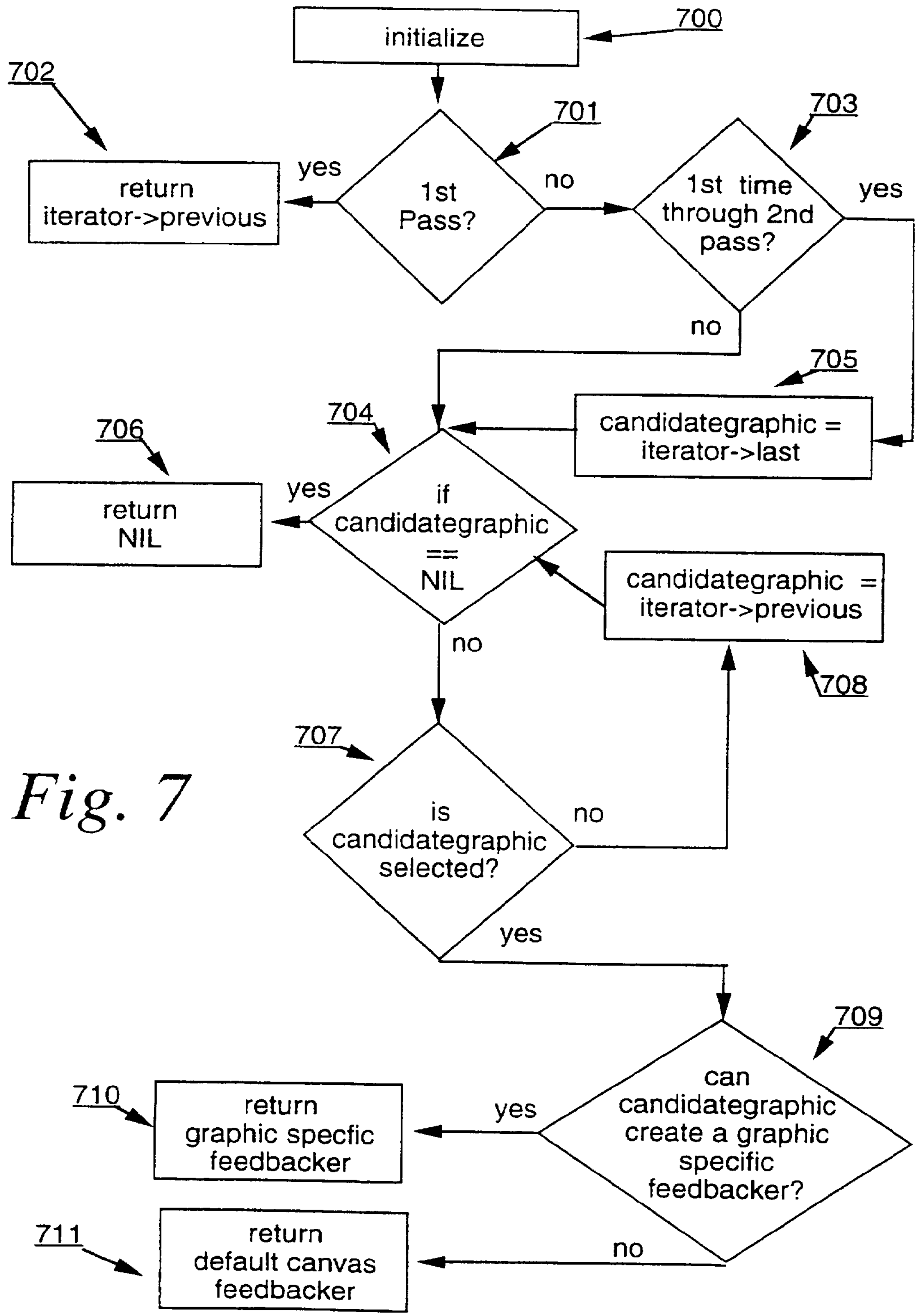

initialize
700
702
701
703
return
iterator->previous
yes
1st
Pass?
no
1st time
through 2nd
pass?
yes
no
705
704
candidategraphic =
iterator->last
706
return
NIL
yes
if
candidategraphic
==
NIL
candidategraphic =
iterator->previous
no
708
707
is
candidategraphic
selected?
no
yes
709
710
return
graphic specfic
feedbacker
yes
can
candidategraphic
create a graphic
specific
feedbacker?
711
return
default canvas
feedbacker
no

Fig. 7

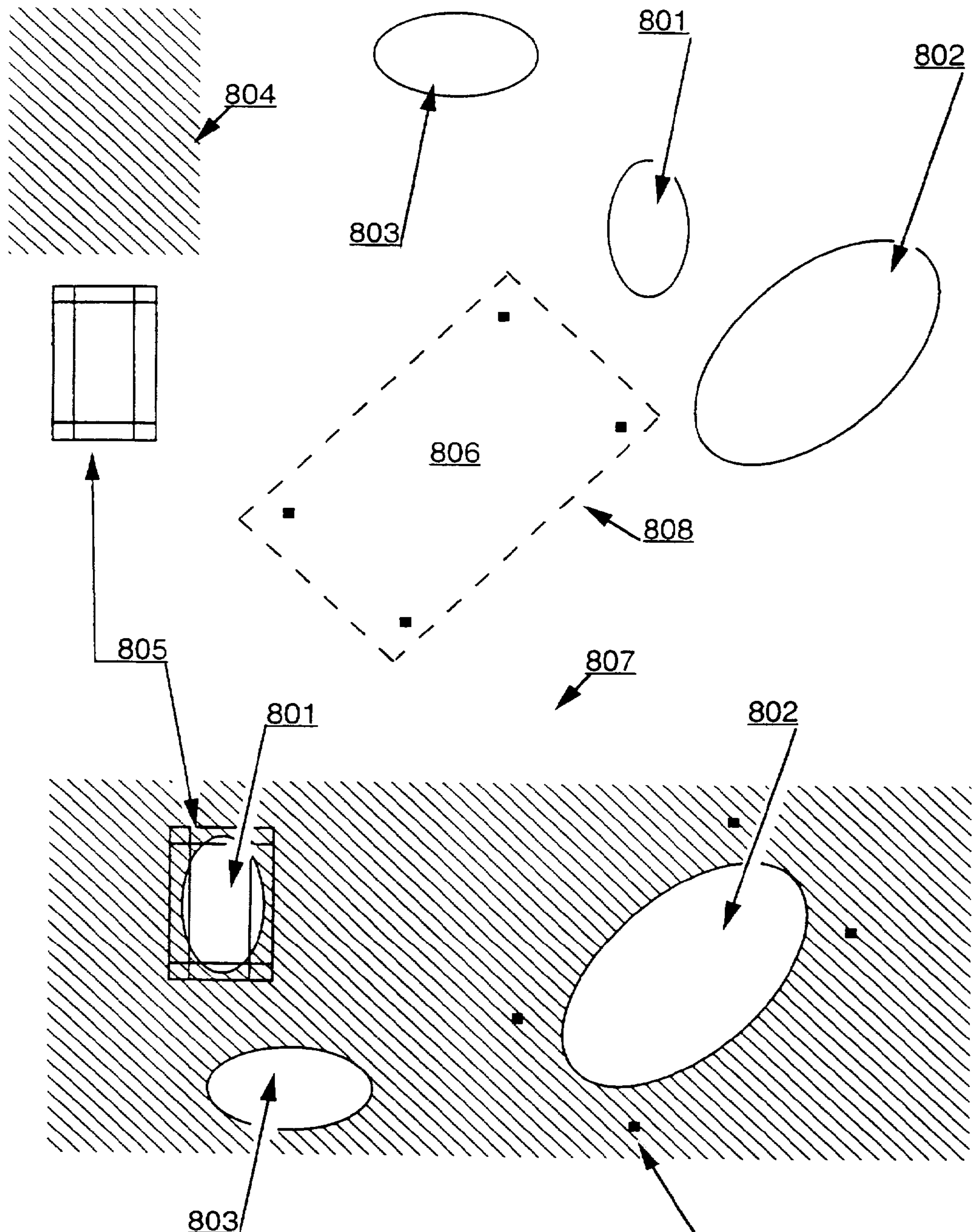


Fig. 8

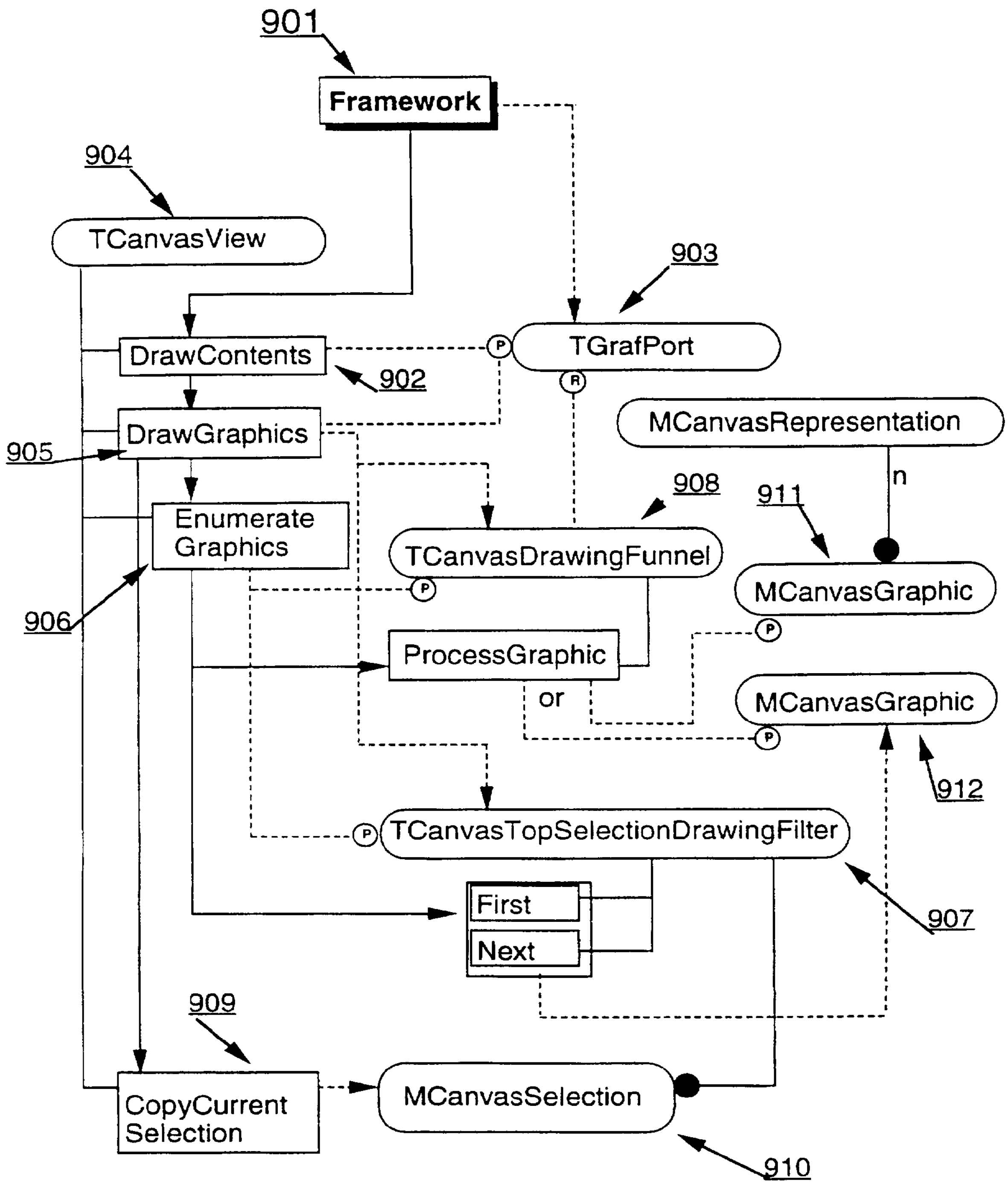

901
Framework
904
TCanvasView
903
DrawContents
TGrafPort
902
DrawGraphics
MCanvasRepresentation
905
n
908
911
Enumerate Graphics
TCanvasDrawingFunnel
MCanvasGraphic
906
ProcessGraphic
or
MCanvasGraphic
912
TCanvasTopSelectionDrawingFilter
First
Next
907
909
CopyCurrent Selection
MCanvasSelection
910

Fig. 9

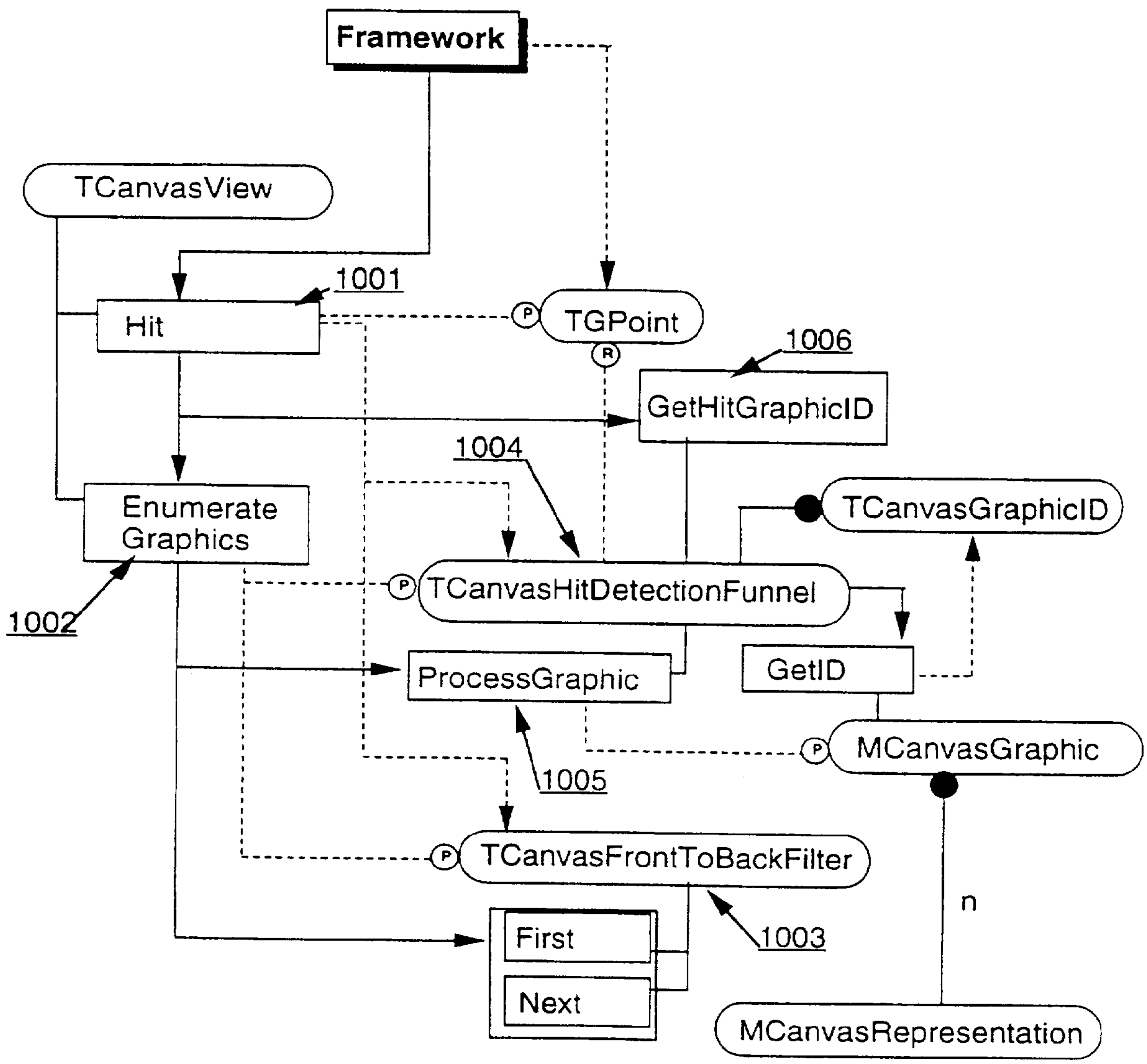

Framework
TCanvasView
Hit
1001
TGPoint
P
R
1006
GetHitGraphicID
1004
Enumerate Graphics
TCanvasGraphicID
1002
TCanvasHitDetectionFunnel
ProcessGraphic
GetID
MCanvasGraphic
1005
TCanvasFrontToBackFilter
n
First
Next
1003
MCanvasRepresentation

Fig. 10

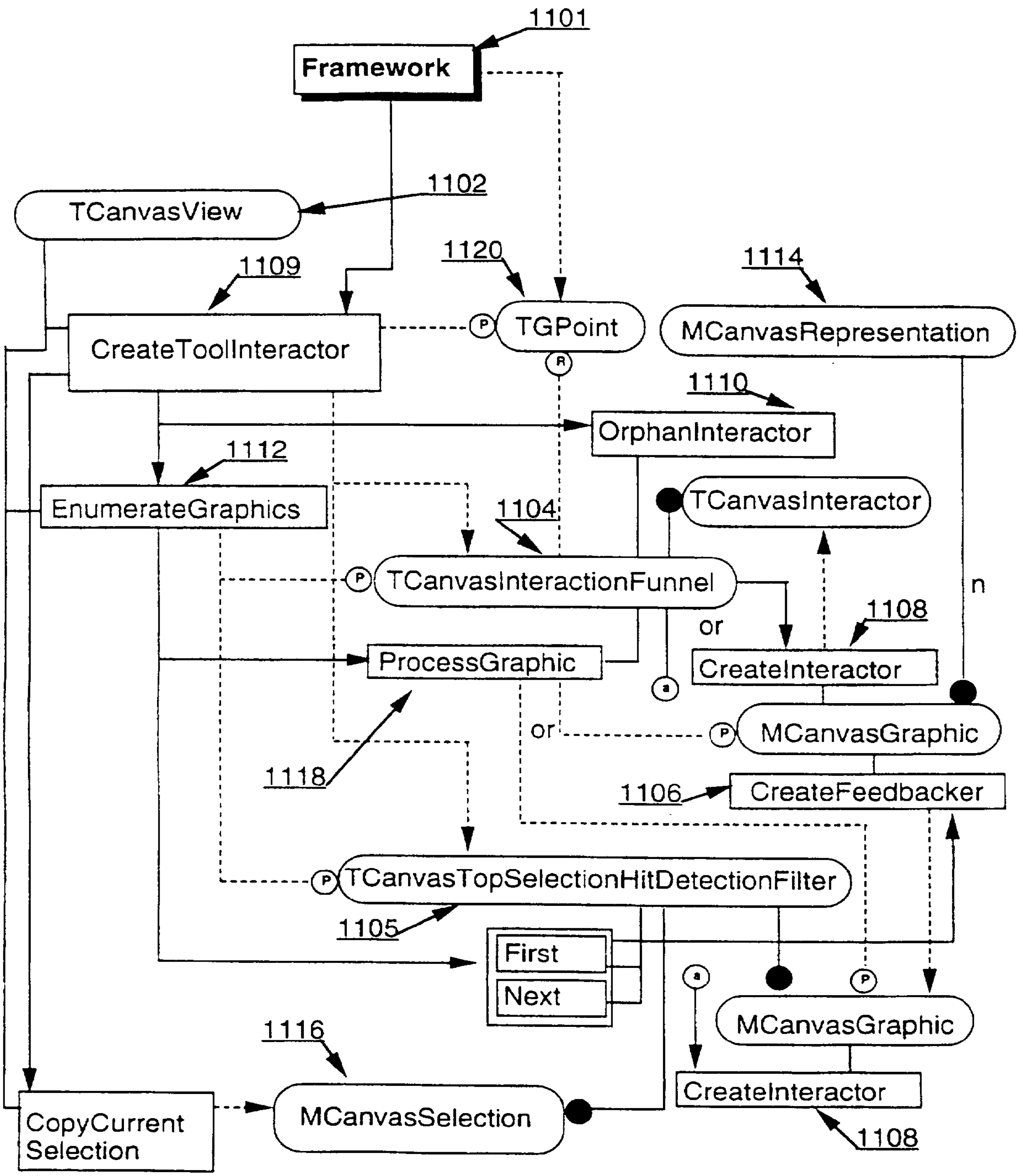

1101
Framework
1102
TCanvasView
1109
CreateToolInteractor
1120
TGPoint
1114
MCanvasRepresentation
1110
OrphanInteractor
1112
EnumerateGraphics
TCanvasInteractor
1104
TCanvasInteractionFunnel
n
1108
or
ProcessGraphic
CreateInteractor
or
MCanvasGraphic
1118
1106
CreateFeedbacker
TCanvasTopSelectionHitDetectionFilter
1105
First
Next
MCanvasGraphic
1116
CreateInteractor
CopyCurrent Selection
MCanvasSelection
1108

Fig. 11

INTERNATIONAL SEARCH REPORT

Inter nal Application No
PCT/US 96/17221

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G06F9/44 G06F3/033

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO,A,95 12161 (TALIGENT INC) 4 May 1995 cited in the application see page 9, line 3 - page 10, line 5; figures 3A,,3B -----	1,10,11, 20,22,27

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 January 1997	11. 02 97

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INTERNATIONAL SEARCH REPORT

Inter   nal Application No
PC1/US 96/17221

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO-A-9512161	04-05-95	AU-A- 6019194	22-05-95
		EP-A- 0712513	22-05-96